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Original communication

A study of sex differences in fingerprint ridge density in a North Indian young adult population

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ABSTRACT

Fingerprints have considerable value in morphological, biological, anthropological and forensic studies. Fingerprints collected from the crime scene and from the items of evidence of crime have been successfully used to identify suspects, victims or any other person who had touched the surface in question. The thickness of epidermal ridges varies between individuals; females are supposed to have finer ridges than males and therefore a greater ridge density. The present research is an attempt to distinguish sex from fingerprint ridge density in the radial, ulnar and lower areas of a fingerprint in a North Indian population. A total of 194 individuals (97 males and 97 females) aged between 18 and 25 years were included in the study and fingerprints were collected from each finger of the participants. Thus, a total of 1940 fingerprints were obtained and epidermal ridges were counted in the radial, ulnar, and lower areas of each fingerprint. The radial and ulnar areas are the 5 mm × 5 mm areas on the radial and ulnar side of the central core respectively while the lower area is designated as 5 mm × 5 mm area adjoining the flexion crease of the terminal phalanx on a fingerprint. The fingerprint ridge density in radial, ulnar and lower areas and between sexes was compared statistically using *t*-test. The results indicate that the females tend to have a significantly higher ridge density than males in the three areas analyzed in the study. The fingerprint ridge density in the ulnar and radial areas of the fingerprints is significantly higher than the lower area. The present study suggests that the fingerprint ridge density can be a relevant and useful morphological parameter in distinguishing sex of a latent fingerprint of unknown origin from the scene of crime. The findings can also be useful in identification of mutilated remains when a dismembered hand is brought for medico-legal examination.

1. Introduction

Dermatoglyphics has long been considered as an important morphological trait for studying individual variation within the domain of biological anthropology, human biology, morphology and anatomy.[1–5] Previous studies have shown the utility of dermatoglyphics and its possible role in the diagnosis of genetic and medical disorders.[6–12] Variations in fingerprint patterns among various population groups have been reported.[13–15] Fingerprints are permanent morphological characteristics and criminal detection based on fingerprints is based on the principle that no two people can have identical fingerprints.[16] Fingerprints have been widely and universally used in forensic examinations as positive proof of identity by different law enforcing agencies for more than a century now.[17] While comparing the fingerprints of the suspects with the latent fingerprints found at the crime scene, the fingerprint examiners usually study the ridge counts and ridge characteristics. Consequently, these two characteristics of the fingerprints have been widely studied by the researchers and analysts.[18–20]

Fingerprint ridge density is another characteristic feature of considerable importance in fingerprints. Fingerprint ridge density is defined as the fingerprint ridge count corresponding to a defined fingerprint area. It is determined by two parameters; ridge width and distance between ridges.[20] A few studies have examined variability in fingerprint ridge density with respect to its application in determination of sex.[20–24] Applicability of fingerprint ridge density in determination of sex is based on the fact that the females

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tend to have finer ridge detail on fingers, therefore more ridges than males.

Acree[21] analyzed fingerprint ridge density on the radial side of fingerprints in 400 Caucasian and African American males and females aged between 18 and 67 years. The findings of the study indicated that fingerprint ridge density in females was significantly higher than males. The study further concluded that a given fingerprint possessing a ridge density of 11 ridges/25 mm^2 or less was most likely a male and a ridge density of 12 ridges/25 mm^2 or greater was most likely a female. In a similar study on 500 subjects from South India, Gungadin[22] concluded that a fingerprint density of 13 ridges per 25 mm^2 or less was most likely a male and a ridge density of 14 ridges per 25 mm^2 or greater was most likely a female.

Gutiérrez-Redomero et al.[20] conducted a study to establish a relationship between sex and fingerprint ridge density in 200 Spanish Caucasian males and females aged between 20 and 30 years. They analyzed fingerprint ridge density in a manner described by Acree[21] and besides radial area, the count was extended to ulnar and lower part of the fingerprint. The study concluded that females tend to have a significantly higher ridge density than males in the distal region of the fingerprint (radial and ulnar areas), but not in the proximal region (lower area). They calculated likelihood ratio to obtain probability inference of sex based in ridge density and observed that in radial area, dermal ridge count of 16 ridges/25 mm^2 or less was most likely to be of male origin, and a ridge count of 17 ridges/25 mm^2 or more was most likely to be of female origin. In ulnar area, dermal ridge count of 14 ridges/25 mm^2 or less was most likely to be of male origin, and that a ridge count of 17 ridges/25 mm^2 or more was most likely to be of female origin.

In a study on 100 males and 100 females from South India aged between 18 and 25 years, Nayak et al.[23] suggested that fingerprint ridge density may be a useful clue in identification of a suspect. In this study, the upper portion on the radial border of a fingerprint was analyzed according to the study conducted by Acree.[21] The study indicated that a mean fingerprint ridge density of 12 ridges/25 mm^2 or less was more likely to be of male origin and a mean ridge count of more than 12 ridges/25 mm^2 was more likely to be of female origin.

A recent communication,[25] suggests various environmental and genetic causes for sex differences in fingerprint ridge density and proposes further research on an appropriate sample in different ethnic groups to find the exact cause and kind of variability in fingerprint ridge density among males and females. The present research was planned to analyze fingerprint ridge density in a North Indian population, keeping in view the fact that population based differences exist in fingerprint ridge density and that no studies are available on the variability and sex differences in the of fingerprint ridge density in the three areas analyzed by Gutiérrez-Redomero et al.[20] Moreover, with regard to sex differentiation, variations in fingerprint ridge density in each finger have not been presented earlier. The present research evaluates the variability of fingerprint ridge density in the radial, ulnar and lower area of fingerprints and compares fingerprint ridge density in various fingers in individuals from North India. The present study also evaluates the differences in fingerprint ridge density between right and left hands. The research aims to find the sex differences based on fingerprint ridge density and its possible applicability in the determination of sex in forensic examinations.

2. Material and methods

2.1. Study participants

Fingerprints were collected from 194 students (97 males and 97 females) aged between 18 and 25 years from different schools and colleges of Palampur city, District Kangra in the State of Himachal Pradesh in North India. Most of the participants belong to agricultural families with animal husbandry as a secondary occupation. Mean age (±S.D.) of male and female participants was 21.2 (±1.9) years and 20.9 (±2.1) years respectively.

2.2. Analysis of the fingerprints

The fingerprints were obtained from the participants by means of simple inking method as suggested by Cummins and Midlo.[26] A total of 1940 fingerprints were obtained from 194 males and females. Fingerprints obtained from different digits were denoted as R I, R II, R III, R IV, R V and L I, L II, L III, L IV, L V for thumb, index, middle, ring and little finger respectively on the right and left sides. The ridges on fingerprints were counted diagonally on a square measuring 5 mm × 5 mm according to the method described by Acree[21] and on the areas described by Gutiérrez-Redomero et al.[20] The radial and ulnar areas are 5 mm × 5 mm areas on the radial and ulnar side of the central core respectively while the lower area is designated as 5 mm × 5 mm area adjoining the flexion crease of the terminal phalanx in a fingerprint. For analysis of fingerprint ridge density in radial and ulnar areas a square measuring 5 mm × 5 mm was placed directly on the radial and ulnar side of the central core region respectively in such a way that the lowermost and innermost corner of the square was located on the central core of the fingerprint. For analysis of fingerprint ridge density in the lower area, a line perpendicular to the flexion crease of the terminal phalanx was drawn passing through the core and a square measuring 5 mm × 5 mm was placed diagonally on it with one corner located on the flexion crease. The radial, ulnar, and lower areas included in the study are depicted in Fig. 1. Numbers of ridges were counted diagonally on the 5 mm × 5 mm squares placed on the radial, ulnar and lower areas of the fingerprints obtained from both hands in each individual and the number of ridges per 25 mm^2 of the fingerprint surface was thus, obtained.

2.3. Statistical analysis

The variations observed in the fingerprint ridge density in all the three areas were analyzed according to typological variability, differences between right and the left hand and sexual dimorphism. The fingerprint ridge density in the radial, ulnar, and lower areas were analyzed in each finger of the participants and the mean fingerprint ridge density for each area in each finger was estimated in males and females. The differences in fingerprint ridge density between the sexes were analyzed individually for each finger in both hands and for all ten fingers together. The sample was

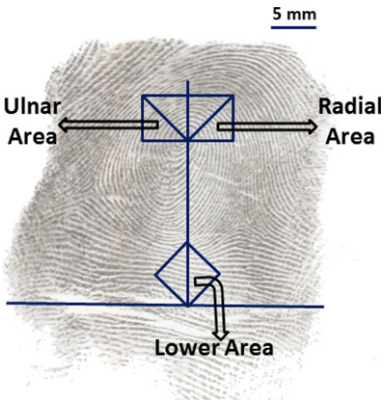

Fig. 1. Radial, ulnar and lower areas on a fingerprint where fingerprint ridge density was analyzed.

Table 1
Sex wise distribution of fingerprint ridge density in radial, ulnar and lower area.

FPRD	Radial area		Ulnar area		Lower area	
	Males *n* (%)	Females *n* (%)	Males *n* (%)	Females *n* (%)	Males *n* (%)	Females *n* (%)
9	–	–	–	–	4 (4.12)	–
10	–	–	–	–	22 (22.68)	2 (2.06)
11	–	–	–	–	25 (25.77)	24 (24.74)
12	1 (1.03)	–	–	–	37 (38.14)	42 (43.29)
13	2 (2.06)	–	2 (2.06)	–	6 (6.19)	25 (25.77)
14	6 (6.19)	–	14 (14.43)	2 (2.06)	3 (3.09)	4 (4.12)
15	30 (30.92)	3 (3.09)	30 (30.92)	7 (7.22)	–	–
16	31 (31.95)	9 (9.28)	40 (41.24)	15 (15.46)	–	–
17	20 (20.62)	21 (21.64)	8 (8.24)	40 (41.24)	–	–
18	6 (6.19)	31 (31.95)	2 (2.06)	23 (23.71)	–	–
19	–	25 (25.77)	–	8 (8.24)	–	–
20	1 (1.03)	7 (7.22)	1 (1.03)	1 (1.03)	–	–
21	–	1 (1.03)	–	1 (1.03)	–	–

FPRD- Fingerprint ridge density.

statistically analyzed using SPSS version 11.0. Student's *t*-test was applied for comparative analysis. '*p*' value of less than 0.05 was considered as significant.

3. Results

Sex wise distribution of fingerprint ridge density in radial, ulnar and lower area is shown in Table 1. It is apparent that the distribution of fingerprint ridge density in radial and ulnar areas is similar with fingerprint ridge density ranging from 12 to 20 and 13–20 among males and 15–21 and 14–21 among females in the radial and ulnar areas respectively. A considerably lower fingerprint ridge density is observed in the lower area (9–14 in males and 10–14 in females) than that observed in the radial and ulnar areas. Extent of overlapping was maximum in the lower area, 63.91% males ($n = 62$) and 68.03% females ($n = 66$) had a fingerprint ridge density of either 11 or 12 in the lower area. In the radial area, maximum overlapping was observed for the fingerprint ridge density value of 17, with 20 males and 21 females having a fingerprint ridge density of 17. Extent of overlapping in the male and female values for fingerprint ridge density was minimum in the ulnar area. Descriptive statistics for fingerprint ridge density in all fingers together in each designated area on a fingerprint are shown in Table 2. It is evident that the mean fingerprint ridge density is maximum in the radial area (males = 15.84, females = 17.94), followed by ulnar area (males = 15.51, females = 17.11) and minimum in the lower area (males = 11.29, females = 12.05). Significant sex differences ($p < 0.001$) were observed between the fingerprint ridge density values observed in radial, ulnar and lower areas. The sex differences are observed to be maximum in the radial area ($t = -11.897$) followed by ulnar ($t = -9.776$) and lower areas ($t = -5.332$). Distribution of fingerprint ridge density in each area is shown in Fig. 2.

Table 2
Descriptive statistics and *t*-test for fingerprint ridge density in the three areas analyzed in all fingers among males and females.

Sex		Radial area	Ulnar area	Lower area
Male	*n*	97	97	97
	Mean	15.84	15.51	11.29
	S.D	1.231	1.081	1.108
	Range	12–20	13–20	9–14
	Median	16.00	16.00	11.00
Female	*n*	97	97	97
	Mean	17.94	17.11	12.05
	S.D	1.232	1.207	0.870
	Range	15–21	14–21	10–14
	Median	18.00	17.00	12.00
t-test		−11.897*	−9.776*	−5.332*

S.D- Standard Deviation, *- $p < 0.001$.

When each finger was analyzed individually for sex differences in the fingerprint ridge density, it was observed that statistically significant sex differences ($p < 0.001$) exist in the fingerprint ridge density of each individual finger in the radial, ulnar and lower areas in both hands. Descriptive statistics and *t*-test results for the fingerprint ridge density in the radial, ulnar and lower areas of individual fingers in males and females are shown in Tables 3–5 respectively. It is further observed that fingerprint ridge density varies between different fingers in the radial, ulnar and lower areas analyzed in the study. In the radial and ulnar areas, the fingerprint ridge density was minimum in the thumb and maximum in the ring finger followed by little finger in right and left hands among males and females. In the lower area, the fingerprint ridge density was maximum in the thumb in both hands among males and females whereas, minimum fingerprint ridge density was observed in the middle finger in the right hand and in the little finger in the left hand among males and females.

4. Discussion

The present study reports a significantly lower fingerprint ridge density in the lower area than in the radial and ulnar areas. The lower ridge density may be indicative of thicker ridges/wider valleys or a combination of both features in the lower area. Ohler and Cummins[27] observed that the ridge widths are finest on the fingertips, coarser in the distal palm, and coarsest in the proximal palm in both males and females. Our observations that the three areas on fingerprints exhibit differences in the fingerprint ridge density is similar to that reported by Gutiérrez-Redomero et al.[20] in the only other similar study available in literature. Jantz and Owsley[28] proposed that the differences in the ridge counts reflect that the different areas of the digits apparently respond to different developmental instructions. Findings of the present study did not show any marked differences between the fingerprint ridge density in the left and right hands. In studies conducted by Ohler and Cummins[27] and Cummins et al.,[29] the ridges of right hand were found to be coarser than the left hand. Thus, for the same area, the right hand would have a fewer ridges than the left hand.

Statistically significant sex differences are observed in the fingerprint ridge density in the radial, ulnar, lower areas analyzed in the study. The females have a higher fingerprint ridge density than males in all the three areas. Our findings are in agreement with the recent studies conducted on fingerprint ridge density that

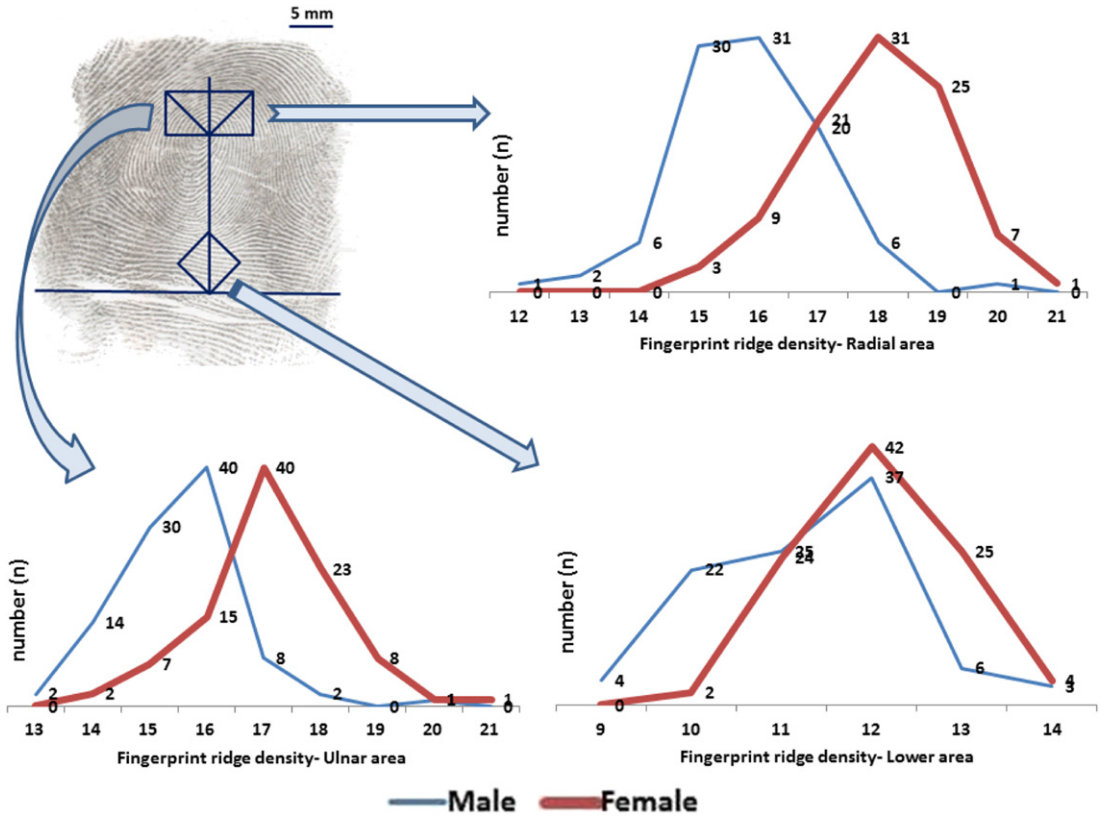

Fig. 2. Frequency distribution of fingerprint ridge density in the radial, ulnar and lower areas of a fingerprint.

report a higher fingerprint ridge density among females in the outer area of a fingerprint.[20–24] Thus, even when the areas analyzed for fingerprint ridge density in our study differs from that of the earlier studies[20–24] the basic quantitative differences in the ridge density remains the same, females having a higher fingerprint ridge density than males. The higher fingerprint ridge density in females is attributed to the fact that females tend to have finer epidermal ridges than males. Males generally have coarser ridges than females and the difference is approximately 10%.[30] According to Králík and Novotný[30] and Penrose and Loesch,[31] an increase in the number of X-chromosomes, causes an increase in the ridge density, therefore, it seems consistent to propose that ridge density is a quantitative genetic trait at least a major part of whose genes lie in the sex chromosomes. The study[31] also observes that the distance between the ridges increases due to the existence of the Y-chromosome. The observation indicates that not only is there an increase in the number of ridges among females but also that these ridges are packed more densely in the given area in females. The higher fingerprint ridge density may also be attributed to the proposed fact that on an average, body proportions of males are larger than females, thus, the same numbers of ridges are accommodated among the males in a larger surface area and thus, a resultant lower fingerprint ridge density among males.[25]

When we compare our findings on sex differences in the fingerprint ridge density in the three areas on a fingerprint with the only other similar study[20]; it is apparent that contrary to our observations on significant sex differences in all the three areas, Gutiérrez-Redomero et al.[20] reported significant sex differences only in the distal region (radial and ulnar areas), and not in the proximal region (lower area). Significant overlapping in the male and female values in the lower area observed in our study however, indicates that the sexing potential of fingerprint ridge density in the

Table 3
Descriptive statistics and *t*-test values for fingerprint ridge density in the radial area of each finger in males and females.

Sex		L I	L II	L III	L IV	L V	R I	R II	R III	R IV	R V
Male	*n*	89	79	89	91	94	94	82	94	96	94
	Mean	14.52	15.57	15.87	17.07	16.70	14.35	15.15	15.87	16.80	16.01
	S.D	2.079	1.566	1.707	1.982	1.746	1.993	1.524	1.654	1.448	1.688
	Range	6–17	11–19	10–21	7–22	11–21	7–18	8–19	8–21	14–22	11–22
	Median	15.00	16.00	16.00	17.00	16.00	15.00	15.00	16.00	17.00	16.00
Female	*n*	90	86	89	94	94	94	86	94	95	96
	Mean	15.83	17.60	18.51	19.41	18.64	15.85	16.94	18.37	18.99	18.03
	S.D	2.724	1.784	1.686	1.892	2.058	1.820	1.724	1.444	1.825	1.954
	Range	7–20	8–21	14–22	12–24	7–23	9–19	7–20	14–22	12–23	14–29
	Median	16.00	18.00	19.00	20.00	19.00	16.00	17.00	18.00	19.00	18.00
t-test		−3.632*	−7.757*	−10.382*	−8.247*	−6.956*	−5.389*	−7.138*	−11.038*	−9.181*	−7.620*

S.D- Standard Deviation, *- $p < 0.001$.

Table 4
Descriptive statistics and *t*-test values for fingerprint ridge density in the ulnar area of each finger in males and females.

Sex		L I	L II	L III	L IV	L V	R I	R II	R III	R IV	R V
Male	*n*	90	78	89	92	95	93	82	94	96	94
	Mean	13.73	14.76	15.83	17.11	15.97	14.02	14.79	15.86	16.69	15.80
	S.D	1.270	1.388	1.517	1.515	1.601	1.622	1.264	1.426	1.496	1.388
	Range	11–17	11–19	12–22	13–24	11–23	10–20	12–19	13–21	13–22	13–21
	Median	14.00	15.00	16.00	17.00	16.00	14.00	15.00	16.00	17.00	16.00
Female	*n*	90	86	89	95	94	94	86	94	96	96
	Mean	14.94	16.41	17.61	19.22	17.73	15.06	16.38	17.33	18.53	17.42
	S.D	2.294	2.254	2.307	1.625	1.539	1.664	1.588	1.562	1.903	1.594
	Range	10–18	13–20	14–22	15–23	14–21	11–19	13–20	13–21	11–23	13–22
	Median	15.00	16.00	18.00	19.00	18.00	15.00	16.00	17.00	19.00	17.00
t-test		−5.445*	−7.521*	−8.171*	−9.185*	−7.728*	−4.337*	−7.163*	−6.730*	−7.464*	−7.460*

S.D- Standard Deviation, *- $p < 0.001$.

Table 5
Descriptive statistics and *t*-test values for fingerprint ridge density in the lower area of each finger in males and females.

Sex		L I	L II	L III	L IV	L V	R I	R II	R III	R IV	R V
Male	*n*	90	78	89	91	95	93	82	94	96	94
	Mean	11.71	11.45	10.72	11.08	10.48	11.83	11.76	10.95	11.70	11.12
	S.D	1.478	1.483	1.492	1.335	1.472	1.515	1.243	1.582	1.459	1.269
	Range	8–15	8–16	7–14	8–14	7–15	8–15	8–15	8–15	9–15	8–14
	Median	12.00	11.00	10.00	11.00	10.00	12.00	12.00	11.00	11.00	11.00
Female	*n*	90	84	89	95	94	94	87	94	95	96
	Mean	12.62	12.24	11.49	11.87	11.30	12.62	12.21	11.74	12.14	11.95
	S.D	1.511	1.199	1.235	1.290	1.285	1.183	1.348	1.200	1.285	1.325
	Range	9–19	9–14	8–14	9–16	8–15	10–15	8–15	9–16	8–15	8–14
	Median	13.00	12.00	12.00	12.00	11.00	13.00	12.00	12.00	12.00	12.00
t-test		−4.089*	−3.738*	−3.776*	−4.139*	−4.046*	−3.971*	−2.256#	−3.896*	−2.205#	−4.414*

S.D- Standard Deviation, *- $p < 0.001$, #- $p = 0.03$.

lower area of a fingerprint is very limited. Variations in the fingerprint ridge density values among the Indian population in the present research and the Spanish population reported in the earlier study[20] confirms the view that population differences exist in fingerprint ridge density.

The present study observes that the fingerprint ridge density varies considerable in each finger of the hand and in different areas analyzed in the study in both males and females. The fingerprint ridge density was minimum in the thumb and maximum in the ring finger followed by little finger in the radial and ulnar areas. Findings of our study supports the observations made in the earlier studies[27,28] that showed a higher ridge breadth in thumb than the other fingers, the order of the decreasing ridge breadth being thumb followed by index, middle, little and ring finger. Contrary to their observations however, the fingerprint ridge density was maximum in the thumb in in the lower area and minimum in the middle finger of right hand and the little finger of the left hand among males and females in the present study. Statistically significant sex differences in the individual fingers are observed in the radial, ulnar and lower areas analyzed in the study. The fingerprint ridge density and the extent of sexual dimorphism vary between different fingers and in the different areas. To the best of our knowledge, this is the first study that reports sex differences in the fingerprint ridge density of each finger in the three areas and hence, the findings of the present study cannot be compared per se with the earlier studies that have reported sex differences in the fingerprint ridge density from the mean values of all ten fingers taken together.[20–24]

5. Conclusions

The present research confirms that fingerprint ridge density is a variable morphological trait in individuals and can be considered as an attribute for determination of sex in forensic examinations. The females have a significantly higher fingerprint ridge density than males in radial, ulnar and lower areas of a fingerprint and that the fingerprint ridge density in the ulnar and radial area of the fingerprints are significantly higher than the lower area in the North Indian population. The study also shows that individual variations exist in the fingerprint ridge density in each finger in the three different areas. The findings of the present study thus, suggest that the fingerprint ridge density can be a relevant and useful parameter in determining sex of a latent fingerprint of unknown origin from the scene of crime. The findings can also be useful in identification of mutilated remains when a dismembered hand is brought for medico-legal examination.

Our findings on the variations in the fingerprint ridge density in individual fingers emphasize on the need to analyze each finger individually in future researches on the subject. It is suggested that due to genetic and environmental variability inherent in human populations inhibiting the different geographic regions of world, there is a need to conduct similar studies in different population groups to generate statistical standards for each population.

Ethical approval

None declared.

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Conflict of interest

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